Smart Whcal-1'lane Technology for Micro-Instrum cnts and Micro-Rovers

Eric R Fossum
Jet Propulsion 1 ,aboratory
California Institute of Technology

It is inevitable that micro-instruments and micro-rovers for space exploration will contain onc or more f'ocal-plane arrays for imaging, spectroscopy or navigation. in this paper, wc explore the sla[c-of-the-arl in focal-plane technology for visible sensors. Also discussed is present research activity in advanced focal-plane technology with particular emphasis on the development of smart sensors. The paper concludes with a discussion of possible future directions for the advancement of the technology.

Visible focal-plane technology is currently dominated by charge-coup]cd devices (CCDs). The CCD can be used for both photon detection and as a readout multiplexer since its primary function is the shifting of charge packets. Scientific CCDs typically employ both modes of operation to utilize the maximum amount of chip area for the collection of photons and arc rout incly made in megapixel array sizes, with the largest demonstrated CCD size being 16 Mpixels.[1] Unfortunately, the elect rodes which comprise the CCD ancl ensure high fidelity of the readout signal also block photons, particularly in the blue and ultraviolet (U V). Thus, separation of the sensor into a photoactive portion and a readout portion is often used to enhance the spectral response. The photoactive region may be a pinned photodiode[2] to obtain high blue response (or a platinum-silicide Schottky diode to obtain infrared response[3]). The readout CCD lies between photoactive regions and is typically covered by a metallic light shield, Thinning the chip to enable the back side of the chip to operate as the photoactive region has also been employed to enhance blue and UV (and infrared) response.[4] Such a structure is mechanically fragile however.

'1'here arc major disadvantages to the CCD. In large array sizes, signal charge must be physically t ransported macroscopic distances (centimeters) without significant loss of fidelity, making CCD application in high radiation environments, low temperature environments, and high frame rate systems difficult to achieve. Additionally, voltages applied to the CCD arc typically large (10-20 volts) and must cl rive high capacitance loads, making integrat ion of timing and control signal generators and clock drivers with the image sensor nearly impossible.

The emergence of the high -definit ion television (HDTV) concept has driven commercial research and advanced development of image sensors away from the CCD and toward alternative approaches. '1 'he primary approach is the active pixel sensor[5] because it avoids the physical transport of charge. The pixel is addressed for readout in random access fashion, i.e. by its X-Y address. The pixel consists of both the photoactive region and a readout transistor. The rcadont transistor senses the voltage developed in the photoactive region, and is read out in voltage-fo]lowcr mode. The two components arc often vertically integrated to maximize the size of the photoactive region. Transistor approaches to the active pixel sensor include MOSFETs,[6] S11's,[7] and 111'1's.[8] The active pixel sensor allows small, highly sensitive pixels, high readout rates, and, in principle, improved operation in high radiation environments and at low temperat arcs. The act ive pixel sensor also requires lower drive voltages and lower capacitance drive]s thus permitting on-chip integration of both timing and drive electronics.

1 ntegrability of drive electronics also implies the integrability of post-image-capture image and signal processing circuitry. The purpose of on-chip integration of signal processing in scientific instruments is to enhance the signal-to-noise ratio. Integration, in general, also decreases system size and weight and increases reliability - important issues for micro-instruments. For example, on-chip signal processing has been demonstrated for enhancing the compressibility of 256x256 images with negligible increase in system complexity.[9] On-chip analog-to-digital conversion, presently under investigation at JPL, for low-light-level imaging, enhances system dynamic range and eliminates all off-chip signal chain electronics. h~ulti-resolution image pyramid generation for rover vision is also king investigated at J}'], for on-chip application. Significant power and weight savings can be achieved in this case as well.

There arc many future directions for smarl focal-plane technology.[10] In the case of micro-instruments, increased signal processing to enhance science return has wide applicability. This processing can include noise reduction, electronic image stabilization,[11] non-uniformity correction, automatic focus, spatial oversampling for higher resolution imaging and on-chip analog-to-digital conversion. Other processing related to nlicro-instruments and micro-rovers includes windowed readout for region-of-interest, higher imaging rates, feature recognition (spatial and spectral) for autonomous mission replanning, stereo-vision processing for range information, and processing for active range sensing systems.

The low power, low weight and small size of future spacecraft and missions will require development of highly integrated, smart fbcal-plane technology. This area will require nurturing to ensure that anticipated future mission requirements can be met.

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